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Galileo and the Scientific Revolution: The Importance of His Kinematics

[*Galilaeana*, 8 (2011), pp. 3-36.]

If asked to sum up Galileo's contribution to the Scientific Revolution, a historian of science might still wish to stipulate Galileo's experimental method, even though the extent to which he relied upon experimental evidence was challenged by his great admirer Marin Mersenne, and was effectively denied by Raffaello Caverni, and of course Alexandre Koyré.¹

Alternatively, our historian might see it as a safer bet to extol his contribution to the «mathematization of the world picture». Regardless of arguments about whether Galileo should be seen as a Platonist or an Archimedean, there can be no denying that, by showing how mathematics can be used to reveal real truths about the physical world, Galileo was one of the greatest of those early modern thinkers who removed the traditional barrier, maintained by scholastic Aristotelians, between a natural philosophy supposedly based on physical causes, and a mathematics that was seen as merely instrumental.² If anyone deserved to be seen as both mathematician and natural philosopher, it was Galileo.

Another way to sum up Galileo's contribution to the Scientific Revolution is simply to focus on those of Galileo's discoveries which we still uphold today: his various astronomical observations, the law of free fall, the isochronism of the pendulum, the parabolic trajectory of projectiles, and other details of his new science of motion. After all, Galileo was no systematist. As Descartes pointed out to Mersenne, on first reading the *Discorsi* in 1639, «he has not investigated matters in an orderly way, and has merely sought explanations for some

¹ For a fuller discussion of critical assessments of Galileo's experimentalist credentials see MICHAEL SEGRE, *In the Wake of Galileo*, New Brunswick, Rutgers University Press, 1991, pp. 44-49.

² There is a still growing body of scholarship on the rise in status of mathematicians and mathematics in the late renaissance and early modern period. It began with ROBERT S. WESTMAN, *The Astronomer's Role in the Sixteenth Century: A Preliminary Survey*, «History of Science», 18, 105-47; but see also, for example, ANNA DE PACE, *Le matematiche e il mondo*, Milan: Franco Angeli, 1993; and PETER DEAR, *Discipline and Experience: The Mathematical Way in the Scientific Revolution*, Chicago: University of Chicago Press, 1995.

particular effects...»³ It might even be argued that this is the best that can be said in favour of Galileo: his importance lay not in establishing a new way of philosophizing but in producing a range of new observations and new arguments which pointed the way to a new philosophy, and enabled others to accomplish it.

It seems to me, however, that there is another way to sum up Galileo's importance in the history of science. I want to suggest that Galileo's significance for the Scientific Revolution rests upon something as wide ranging and expansive as the experimental method or the mathematization of the world picture but which, as far as I know, has not yet been properly acknowledged by Galileo scholars, although it is certainly implicit in many of their commentaries. What I have in mind might be referred to as «Galileo's science of motion», but by this, I do not simply mean the «new science» of motion which he expounded in the *Discorsi*. Galileo was one of the seminal figures of the Scientific Revolution, I want to suggest, because he clearly showed his contemporaries how all physical phenomena might be explained in terms of bodies in motion, and nothing more.⁴ At a time when the learned all over Europe were recognising that Aristotelianism could no longer be sustained, it became increasingly urgent to establish a new physics on new principles. Although Galileo never succeeded in writing his book on the *System of the World* which he announces as forthcoming in his *Siderius Nuncius*,⁵ his *Dialogo sopra i due massimi sistemi del Mondo*, supplemented

³ Descartes to Mersenne, 11 October 1638. C. ADAM and P. TANNERY (eds), *Oeuvres de Descartes*, 12 vols, Paris, Vrin, 1964-1976, vol. II, p. 380.

⁴ When I say this has not yet been properly acknowledged by Galileo scholars, I am not disregarding the wealth of important work on Galileo's «new science» of motion. It seems to me, however, that the focus of this work has tended to be the technical details of Galileo's theory of motion. For an excellent recent example see CARLA RITA PALMERINO and J. M. M. H. THIJSEN (eds), *The Reception of Galilean Science of Motion in Seventeenth Century Europe*, Dordrecht, Springer, 2004. My concern, unlike those of the authors in this collection, is with the wider ethos of Galileo's natural philosophy, which is to say his kinematic natural philosophy, in which motion is presented as the chief, if not the only, causative and explanatory feature of physical phenomena.

⁵ In STILLMAN DRAKE's edition of *Sidereus Nuncius*, in *Discoveries and Opinions of Galileo*, New York, Random House, 1957, this is mentioned by Galileo on pages 43, 45, and 58. Drake implies the book was intended simply to deal with Copernican theory, and suggests it eventually appeared, modified *per force*, as the *Dialogo* (note 14 on p. 43), but it is possible that at this point Galileo envisaged something closer to a complete

by other mature works, including of course the *Discorsi*, demonstrated sufficiently clearly how everything in the physical world could be explained by recourse to nothing more mysterious than motion. As Thomas Hobbes wrote, «Galileus in our time... was the first that opened to us the gate of natural philosophy universal, which is the knowledge of the nature of ‘motion’. So that neither can the age of natural philosophy be reckoned higher than to him.» Galileo’s science of motion was seen as a «natural philosophy universal».⁶

Galileo was not, of course, unique in seeing the importance of kinematics as all that was required to replace Aristotelian natural philosophy. Some contemporary mathematicians may well have foreshadowed him, as well as the early self-styled physico-mathematical philosopher Isaac Beeckmann, and Descartes certainly outstripped him by producing the first fully developed system of kinematic natural philosophy in his *Le monde*, virtually complete when Galileo’s *Dialogo* emerged from the press.⁷ There can be no denying, however, that Galileo’s reputation was such that his ideas were keenly scrutinised by contemporary thinkers. Descartes suppressed *Le monde* (as a result of Galileo’s condemnation) and by the time the fuller exposition of his system, *Principia philosophiae*, appeared in print in 1644, most of its readers would already have been prepared for Descartes’s unyieldingly kinematic approach by Galileo’s theory of the tides and other aspects of the *Dialogo* and the *Discorsi*.

I will examine the development of Galileo’s kinematics in due course, but before that we should consider the context within which Galileo first presented it. In order to understand the contemporary appeal of kinematics to natural philosophers who were unused to the kind of

system of philosophy, comparable to Descartes’s *Le monde*. For a fuller discussion of this work see DRAKE, *Galileo: Pioneer Scientist*, Toronto: University of Toronto Press, 1990, pp. 79-82.

⁶ THOMAS HOBBS, *Elements of philosophy*, in *English Works of Thomas Hobbes of Malmesbury*, 11 vols, London, J. Bohn, 1839-1845, vol. I, pp. viii-ix.

⁷ On Beeckman and Descartes see, for example, STEPHEN GAUKROGER, *Descartes: An Intellectual Biography*, Oxford, Clarendon Press, 1995.

mathematical approach presented by Galileo (especially in the *Discorsi*), we have to consider the alternatives.

Alternatives to Aristotle: Renaissance Speculative Philosophies

Even before 1543, when Copernicus showed (to those willing to listen) how wrong Ptolemy and Aristotle were about the nature of the world system, and Andreas Vesalius indicated that the medical authority figure, Galen, might also be badly mistaken, leading thinkers were already becoming increasingly aware that the closely interwoven traditional system of philosophy was so flawed as to be unsupportable. The recovery by Renaissance humanist scholars of Ancient alternatives to Aristotle made it clear that *il maestro di color che sanno* was only one among several, and for many Ancient thinkers he was far from being supreme. A resulting tendency among the learned, if not to reject authority *tout court* but at least to treat it more circumspectly, led to a new emphasis on observation and experience—an emphasis which was heightened by information brought back from the voyages of discovery and the New World.⁸

One of the most impressive aspects of the Medieval World view was that it was all of a piece—although it was always possible to argue about seeming contradictions or inconsistencies here and there, for the most part it was an entire system of philosophy, comprehensive in scope, and capable at least in principle of explaining all phenomena. As soon as this edifice began to crumble, therefore, it seemed important to replace it with a similar all-encompassing system. When Vesalius showed that there were no pores in the septum dividing the right ventricle from the left ventricle of the heart, he revealed that the whole interconnected physiological system of Galen could not possibly be correct. It did not

⁸ See, for example, KLAUS A. VOGEL, *Cosmography*, in KATHERINE PARK and LORRAINE DASTON (eds), *The Cambridge History of Science, Volume 3: Early Modern Science*, Cambridge, Cambridge University Press, 2006, pp. 469-96.

help to suggest, as Realdus Columbus did, that blood crossed from the right ventricle of the heart to the left via the lungs; and Harvey's discovery in 1628 that the two separate systems of Galen, the venous and the arterial systems, were in fact one system allowing a continuous re-circulation of the blood, only confirmed that Galenism was thoroughly misconceived. But what was there to replace Galenism? Certainly Vesalius, Columbus and Harvey had nothing to put in its place. The first real attempt to provide the required complete system of physiology, and furthermore one which dovetailed seamlessly with a comprehensive system of natural philosophy (as Galen's system of physiology had, closely enough, with Aristotelian natural philosophy) was offered in Descartes's *Traité de l'homme*.⁹

It was only in the Enlightenment that the impulse to provide a comprehensive system of philosophy was decried.¹⁰ Renaissance and early modern thinkers, used to the comprehensive system of scholastic Aristotelianism and its affiliates (most notably Ptolemaic astronomy and Galenic physiology), were still locked into the view that what was required, as Aristotelianism began to collapse, was an equally all-embracing system of philosophy.

If we concentrate on reforming natural philosophers (as opposed to elite mathematical practitioners, among whom we can include Galileo), it seems fair to say that they almost all looked to the occult as the most likely source for the required new system of philosophy. Occult qualities had long been invoked by scholastic philosophers to explain the behaviour of bodies which could not be explained in terms of the so-called manifest qualities of heat, coldness, dryness and wetness. As Aristotelianism increasingly failed to account for new observations and experiences, occult qualities were resorted to more and more frequently. It

⁹ See, for example, ROGER FRENCH, *William Harvey's Natural Philosophy*, Cambridge, Cambridge University Press, 1994; and ROBERT G. FRANK, *Harvey and the Oxford Physiologists*, Berkeley, University of California Press, 1980. Descartes's *Traité de l'homme* was the second part of *Le monde* and was not published until 1662.

¹⁰ Voltaire and the editors of the *Encyclopédie*, Denis Diderot and Jean d'Alembert, for example, began to dismiss Descartes as a builder of romances who was foolishly enthralled by *l'esprit de système*.

must have seemed a small step from here to supposing that the occult qualities which had never been properly discussed, much less explored, by scholastic philosophers perhaps held the key to reforming natural philosophy. Moreover, the re-discovery of the quasi-religious writings attributed to the author already associated with a diffuse body of magical writings, Hermes Trismegistus, led to the belief that Hermes was an Ancient sage who not only promoted the occult but also prefigured Christian doctrines such as the Trinity, the immortality of the soul, and so forth.¹¹

Marsilio Ficino was, of course, immensely influential in the new movement to develop a new comprehensive system of philosophy. His own occultism in many ways set the trend, subsequent thinkers taking up different features of his philosophy and developing it in varied ways.¹² One of the earliest of these would-be systems, and one which became influential in its own right, was presented by Jean Fernel in his *De abditis rerum causis* (1548). The hidden causes of things, according to Fernel, all seemed to derive in some way from the stars.¹³ Similarly, Girolamo Fracastoro, took as his starting point the old occult belief in sympathies, *De sympathia et antipathia rerum* (1546). Girolamo Cardano's *De subtilitate* (1550), and his *De varietate rerum* (1557) do not seem to provide a coherent philosophical system, but are rather compendia illustrating that there are, as Hamlet believed, «more things under heaven and earth... than are dreamt of in your philosophy». There is no denying, however, that the overall impression is that occult traditions have much to offer.¹⁴ Bernardino Telesio's *De rerum natura iuxta propria principia* (1587) assumed that all things are sentient and relied

¹¹ BRIAN COPENHAVER, *Hermetica*, Cambridge, Cambridge University Press, 1992.

¹² See, for example, MICHAEL J.B. ALLEN, and VALERY REES, with MARTIN DAVIES (eds), *Marsilio Ficino: His Theology, His Philosophy, His Legacy*, Leiden, Brill, 2002; and HIRO HIRAI, *Le concept de semence dans les théories de la matière à la Renaissance de Marsile Ficin à Pierre Gassendi*, Turnhout, Brepols, 2005.

¹³ JOHN M. FORRESTER AND JOHN HENRY, *Jean Fernel's On the Hidden Causes of Things: Forms, Souls, and Occult Diseases in Renaissance Medicine*, Leiden, Brill, 2005.

¹⁴ GIROLAMO CARDANO, *De subtilitate libri XXI*, Paris, 1550; *De rerum varietate libri XVII*, Basel, 1557. WILLIAM SHAKESPEARE, *Hamlet*, Act I, Scene 5, ll. 166-7.

heavily on ideas of spirit which derive from the earlier magical philosophy of Ficino.¹⁵ Furthermore, Telesio was a major influence on at least two other thinkers who were indebted to the magical tradition, Tommaso Campanella, author of *De sensu rerum et magia* (1620) and other magical works, and Francis Bacon, whose own system of philosophy, combined Telesian ideas on spirit with alchemical ideas to make what has been described as a semi-Paracelsian cosmology.¹⁶ The inventive group of Italian system-building «nature philosophers», as they are usually known, also included alongside Telesio and Campanella, Francesco Patrizi, and Giordano Bruno. The magical nature of Bruno's world-view is well known, but Patrizi's views are indicated, if not by the title of his great system, *Nova de universis philosophia* (1593) then by the fact that he published it alongside his own translation of Chaldean and Hermetic works, under the title *Magia philosophia* (1593). We can add to these thinkers, more overtly magical thinkers, such as Giambattista della Porta and Cornelius Agrippa, and of course Paracelsus and his numerous followers.¹⁷

Although each of these had their followers, and some were extremely influential, for us, reading them today, they offer nothing that helps us to really understand the physical world. Indeed, it is very difficult for us to imagine that they did anything but hinder progress in scientific understanding. Giordano Bruno, who still commands huge amounts of scholarly attention, was clearly a confused and undisciplined thinker whose inability to recognise a *non*

¹⁵ BERNARDINO TELESIO, *De Rerum Natura iuxta propria principia Libri IX*. Naples, 1586. See also Nicola Abbagnano, *Bernardino Telesio e la filosofia del Rinascimento italiano*, Milan, 1941.

¹⁶ GERMANA ERNST, *Tommaso Campanella: The Book and the Body of Nature*, Dordrecht, Springer, 2010. GRAHAM REES, *Bacon's speculative philosophy*, in MARKKU PELTONEN (ed.), *The Cambridge Companion to Bacon*, Cambridge, Cambridge University Press, 1996. The classic account of magic in the philosophy of Bacon is, of course, PAOLO ROSSI, *Francesco Bacone: dalla magia alla scienza*, Bari, Laterza, 1957.

¹⁷ P. CASTELLI (ed.), *Francesco Patrizi filosofo platonico nel crepuscolo del Rinascimento*, Florence, Olschki, 2002; LUISA MURARO VAIANI, *Giambattista della Porta mago e scienziato*, Milano, Feltrinelli, 1978; PAOLA ZAMBELLI, *Magic and Radical Reformation in Agrippa of Nettesheim*, «Journal of the Warburg and Courtauld Institutes», 39, 1976, pp. 69–103; CHRISTOPHER I. LEHRICH, *The Language of Demons and Angels: Cornelius Agrippa's Occult Philosophy*, Leiden, Brill, 2003; WALTER PAGEL, *Paracelsus: An Introduction to Philosophical Medicine in the Era of the Renaissance*, New York, Karger, 1958; and JOLE SHACKELFORD, *A Philosophical Path for Paracelsian Medicine: The Ideas, Intellectual Context, and Influence of Petrus Severinus (1540/2-1602)*, Copenhagen, The Danish National Library of Science and Medicine, 2004.

sequitur was only matched by his propensity for depending upon them.¹⁸ William Harvey, all too often mistakenly seen as a «modern» thinker who first saw the heart merely as a pump, was in fact a vitalist thinker, led at least in part by his admiration for Fernel, to believe that the blood was inherently alive because it «corresponds to the element of the stars.»¹⁹ Although we can see the links between Harvey's belief and Fernel's *De abditis rerum causis*, we are hard pressed to understand what they really meant by this kind of talk, and why they felt it was useful.²⁰ And yet Fernel and Harvey are among the most down-to-earth of the thinkers mentioned in the previous paragraph. It would be easy to imagine them both rejecting the ideas of other occult philosophers. Indeed, Harvey was known to have had nothing but contempt for Paracelsians.

Francis Bacon, likewise, despised Paracelsus as a promoter of «detestable falsehoods» and «empty delusions». He was willing to make an exception in the case of the Danish Paracelsian Petrus Severinus, however, whom he saw as «a man too good to die in the toils of such folly.»²¹ And yet, when we read Severinus today, although we can acknowledge that his presentation seems more systematic than most Paracelsians, it remains bafflingly unhelpful as a way of understanding the world. It might be suggested, in defence of Severinus, that this is simply because we are too far removed from Severinus historically—and that because of that our mind-sets are too different. But such a suggestion does not capture why we are baffled by Severinus. We can, after all, read Aristotle, or a medieval scholastic, and have no trouble

¹⁸ I am not the only one to have recognised Bruno's inability to offer a cogent argument. For a brief survey of earlier scholars exasperated by Bruno see JOHN HENRY, *Thomas Harriot and Atomism: A Reappraisal*, «History of Science», 20, 1982, pp. 267-96.

¹⁹ WILLIAM HARVEY, *Disputations touching the Generation of Animals*, translated by GWENETH WHITTERIDGE, Oxford, Blackwell Scientific publications, 1981, p. 378. Cf. FORRESTER and HENRY, *Jean Fernel's On the Hidden Causes of Things* (cit. note 13), pp. 34-5.

²⁰ HIRAI, *Le concept de semence* (cit. note 12); and JAMES J. BONO, *Renaissance Theoretical Medicine: Harvey versus Fernel*, «Journal of the History of Biology», 23, 1990, pp. 341-87.

²¹ FRANCIS BACON, *The Masculine Birth of Time*, in BENJAMIN FARRINGTON (ed.), *The Philosophy of Francis Bacon*, Liverpool, Liverpool University Press, 1964, pp. 66-7. For fuller discussion see SHACKELFORD, *A Philosophical Path for Paracelsian Medicine* (cit. note 17), pp. 257-64.

seeing why claims of theirs which we know to be wrong might have been accepted by contemporaries as both persuasive and helpful (take the Aristotelian claim, for example, that a heavy body falls faster than a light one). Severinus's philosophy is just too fanciful, too wilfully and self-referentially convoluted, for us to feel that there is anything reliable in its account of the world. Although Bacon evidently had a grudging admiration for Severinus, it would be easy to imagine another contemporary (and not just a Mersenne, a Galileo, or a Descartes) dismissing it as incoherent nonsense.

It is clear, anyway, that not one among these innovatory thinkers managed to convince the majority of learned men throughout Europe that they had a philosophy which could replace Aristotelianism, lock, stock, and barrel. Nevertheless, taken together, it is clear that they were highly influential. What this collective influence shows, however, is not that there was something in these philosophies, but that the pressing need for some substitute for Aristotelianism was widely recognised. Furthermore, the fact that virtually all of these alternatives were based to a greater or lesser extent on occult notions, provides further testimony to the separation, throughout this period, between natural philosophy and mathematics. So great was this separation that when early modern thinkers began to look for new sources for a reformed natural philosophy, natural philosophers did not think to look to mathematics, as we with hindsight might have expected them to do, but turned more readily to the occult.²²

It is my contention, however, that the proliferation of speculative occult philosophies throughout the sixteenth century and into the seventeenth was another factor enabling mathematicians to make greater claims for the usefulness of mathematics and therefore for

²² I have discussed this in more detail in JOHN HENRY, *The Origins of the Experimental Method—Mathematics or Magic?* in HUBERTUS BUSCHE and STEFAN HESSBRUEGGEN-WALTER (eds), *Departure to Modern Europe: Philosophy between 1400 and 1700* (Hamburg: Felix Meiner, 2010).

their own status in the intellectual and social hierarchies of late Renaissance Europe.²³ Seeing the lack of success of the various occult philosophies, but recognising the pressing need for a new system of philosophy to replace Aristotelianism, some of the most ambitious mathematicians saw their chance to show how their mathematical approach could, in spite of scholastic prejudice against the usefulness of mathematics, provide persuasive accounts of how the world worked. I believe that Galileo was the mathematician who first saw that his mathematical studies could be turned into a new kind of natural philosophy, and one which, presented in the right way, could explain natural phenomena in a way which was immediately intelligible. Galileo's mathematical studies of motion, highly specific and seemingly limited in scope at first—mathematics written for mathematicians—at some point came to be seen by him in a more expansive way. Mathematics, he began to think, could be written for natural philosophers and used as the basis for a *System of the World*. Galileo the natural philosopher came to believe, perhaps as a result of seeing a way to explain the tides, that he could explain all physical phenomena without recourse to the occult, indeed without recourse to anything more mysterious than bodies in motion.

Galileo against the Occult: Denying Forces

I believe the background I have just sketched, showing the proliferation of occult philosophies throughout the sixteenth century, is a major reason why Galileo became so vehemently opposed to the occult. Just as Galileo tried to promote Copernicanism not only by providing evidence and arguments in its favour, but also by dismissing arguments against it; so he tried to promote his own mathematically-inspired philosophy not only by arguments in its support, but also by exposing the inadequacies of any occult approach. Before looking at

²³ The rise in status of mathematical practitioners has been a prominent feature of the literature on early modern science in recent years. See note 2 above, but see also, Mario Biagioli, *The Social Status of Italian Mathematicians, 1450-1600*, «History of Science», 27, 1989, pp. 41-95; and G. C. Giacobbe, *Il commentarium de certitudine mathematicarum disciplinarum di Alessandro Piccolomini*, «Physis», 14, 1972, pp. 5-40.

this in detail, however, it is perhaps worth considering suggestions that early in his career even Galileo might have thought that the occult offered the best chance to find a replacement system of natural philosophy.

The obvious starting point is astrology. It seems hard to believe that Galileo ever took astrology seriously and it is tempting to suppose, therefore, that the horoscopes he cast were done simply because he was commissioned to draw them up. Even those he cast for his own children may have been done at the importuning of Maria, their mother. And yet, it is now clear that the first time the Church authorities took notice of Galileo it included the issue as to whether he was an astrological determinist. An amanuensis to Galileo, Silvestro Pagnoni, testified to the local Inquisition at Padua in 1604 that Galileo declared the predictions based on his nativities to be «certain». The charge was not pursued and so it is possible that there is no truth in it, but given that there is no smoke without fire, it remains puzzling.²⁴ Galileo was such a robust thinker that one cannot help feeling that if he were to believe in astrology, he would want to insist that it was deterministic!—but did he, could he, believe in astrology?²⁵ Galileo again seems to speak positively about astrological influence in a letter he wrote to his supporter Piero Dini in 1611. Dini had asked Galileo what purpose was served by the stars which Galileo had seen through the telescope but which were invisible to the naked eye.

Galileo replied that

if the stars do operate and influence principally by their light, perchance it might be possible with some probable conjecture to deduce courage and boldness of heart from

²⁴ ANTONINO POPPI, *Cremonini e Galilei Inquisiti a Padova nel 1604*, Padua, Antenore, 1993, p. 54.

²⁵ The standard line among astrologers, of course, was that the stars impel but do not compel (*stellae non cogunt, agunt*).

very large and vehement stars, and acuteness and perspicacity of wit from the thinnest and almost invisible lights.²⁶

It may be, however, that Galileo simply did not think the occasion of this letter was the time or the place to dismiss astrology—he might have known, for example, that to do so would merely upset Dini.

Whatever the situation earlier in his career, however, we can now be reasonably certain that by the time he came to publish the *Dialogo* Galileo did not believe in astrology. As well as the famous rejection of astrology in the *Dialogo* itself, we now have the testimony of Ascanio Piccolomini, the archbishop of Siena who took Galileo into his home immediately after his condemnation. In a recently discovered letter of September 1633 to his brother, Ottavio, the archbishop wrote of his own newly inspired rejection of astrology:

I have largely lost credence since learning that Messr. Galileo, famed as an Astrologer and still my guest after two months, derides it entirely, and makes fun of it as a profession founded on the most uncertain, if not false, foundations.²⁷

So much for astrology, but there is a slightly different aspect of heavenly influence we also need to consider. There seems to be an indication that even as late as 1615 Galileo was willing to countenance some kind of heavenly influence capable of acting at a distance. Although, once again, it is difficult to be sure what to make of this pronouncement—it might have been said, insincerely, merely for effect. It occurs towards the end of the *Letter to the*

²⁶ Galileo to Piero Dini, 21 May 1611. For a fuller consideration of Galileo and astrology see Nicholas Campion and Nick Kollerstrom (eds), *Galileo's Astrology*, a special issue of «Culture and Cosmos», 7 (2003). The letter to Dini is discussed pp. 85-95.

²⁷ Ascanio Piccolomini to Ottavio Piccolomini, 22 September, 1633; quoted from MASSIMO BUCCIANINI and MICHELE CAMEROTA, *Once More about Galileo and Astrology: A Neglected Testimony*, «Galilaeana», 2, 2005, pp. 229-231, p.231. I am very grateful to Professor Franco Giudice for bringing this to my attention. See also GALILEO GALILEI, *Dialogue Concerning the Two Chief World Systems*, translated by STILLMAN DRAKE, Berkeley, University of California Press, 1967, pp. 109-10 (OG, VII, pp.135-6).

Grand Duchess Christina, when Galileo is trying to show that the famous Biblical passage in which Joshua commands the Sun to stand still actually fits the Copernican scheme more readily than the Ptolemaic:

if we consider the nobility of the sun, and the fact that it is the font of light which (as I shall conclusively prove) illuminates not only the moon and the earth but all other planets, which are inherently dark, then I believe that it will not be entirely unphilosophical to say that the sun, as the chief minister of Nature and in a certain sense the heart and soul of the universe, infuses by its own rotation not only light but also motion into other bodies which surround it. And just as if the motion of the heart should cease in an animal, all other motions of its members would also cease, so if the rotation of the sun were to stop, the rotations of all the planets would stop too.²⁸

Galileo seems to have borrowed this idea from Kepler's *Astronomia nova* (1609) but he does not support it by reference to Kepler but by reference to «the blessed Dionysius the Areopagite in his book *Of the Divine Names*».²⁹ After two long quotations from Pseudo-Dionysius, Galileo feels justified in concluding: «The sun, then, being the font of light and the source of motion... »³⁰ Wilbur Applebaum and Renzo Baldasso have taken this passage to indicate Galileo's acceptance of Kepler's view, but I remain sceptical.³¹ It seems to me that Galileo was ingenious enough to notice how Kepler's view dovetailed nicely with that of the «blessed Dionysius» and may have appropriated Kepler's view simply to provide him with the occasion of introducing Dionysius into the proceedings. If so, we cannot be confident that Galileo actually believed the Keplerian account, depending as it does upon the supremely occult notion of action at a distance.

²⁸ In DRAKE (ed.), *Discoveries and Opinions of Galileo* (cit. note 5), pp. 212-3.

²⁹ Now attributed, of course, to Pseudo-Dionysius.

³⁰ In DRAKE (ed.), *Discoveries and Opinions of Galileo* (cit. note 5), pp. 213.

³¹ WILBUR APPLEBAUM and RENZO BALDASSO, *Galileo and Kepler on the Sun as Planetary Mover*, in JOSE MONTESINOS and CARLOS SOLIS (eds), *Largo campo di filosofare: Eurosymposium Galileo 2001*, Las Palmas, Fundacion Canaria Orotava de Historia de la Ciencia, 2001, pp. 381-90.

Astrology and the use of Kepler's idea of the sun as the motor of the planetary system are, as far as I know, the only two aspects of Galileo's philosophy which might be construed as occultist. It is impossible to be certain what to make of either of them, but I hope I have said enough to suggest that we might be making a serious mistake if we took either of these at face value. The balance of the evidence with regard to both astrology, and the movement of the planets, is that he did not believe in an occult influence from the heavens, or from heavenly bodies such as the Sun. Certainly, as we shall now see, in every other aspect of his work, Galileo took great pains to eschew any suggestion of occult influence.

The most obvious and unrelenting way in which Galileo denies the occult in his work is by denying the validity of notions of force. It is generally acknowledged that Galileo tried as much as possible to avoid the use of, or even discussions of, force in his natural philosophy. Instead, he tried to develop a physics based upon the causal action of moving bodies, or upon the tendencies of bodies to move. So, although he spoke of force of impact, or force of percussion, and other commonplace notions of force, such as the force required to depress a lever, he avoided talking in terms (familiar elsewhere) of forces as agents which can be disseminated in a sphere of influence or sphere of activity around a non-moving body, or which are capable of acting at a distance. I will say more about these and other similar notions of force later, but for now let me say that this is the kind of force we are concerned with here. So when I say Galileo rejects the notion of force, I do not mean to say that he rejected notions of force of impact and the like, I mean that he rejected notions of force which seem to imply that forces have a real and separate existence of their own.

According to Stillman Drake, Galileo abandoned the notion of force as a cause of motion in 1598 «and never returned to it».³² Drake even went so far as to suggest that the most revolutionary aspect of Galileo's physics was the fact that it was based on a rejection of «causal enquiries», and it seems that what he meant by this was simply that Galileo rejected the notion of force, and developed a «kinematics without any trace of dynamics». So, when Drake wrote of Galileo's «rejection of the quest for causes in physics», he had in mind Galileo's rejection of the explanatory use of force.³³

Drake expressed his surprise at Galileo's approach because, as he himself said, «so deeply ingrained is the notion that little can be done in physics except by dynamics».³⁴ It seems abundantly clear, nonetheless, that Galileo did insist upon developing a kinematic physics and deliberately avoided any recourse to notions of forces in his physical explanations. What is far from clear, however, is why this was so. Little or no attention has been paid by scholars to the reasons for this avoidance of the notion of force. Why was Galileo so concerned to eschew the use of force? Surely this is a question which demands attention. Galileo evidently believed that a kinematic physics was entirely possible. But the question remains, why was this so important to him? Why was it that he preferred to reject the easily available notion of force and to try to proceed without it, even to the detriment of his physics?³⁵

I believe the answer to this question is very simple, even very obvious. Indeed, perhaps so obvious that nobody has bothered to examine it before. It seems to me, however, that just

³² DRAKE, *Galileo: Pioneer Scientist* (cit. note 5), p. 221.

³³ STILLMAN DRAKE, *Cause, Experiment and Science*, Chicago, University of Chicago Press, 1981. DRAKE, *Galileo: Pioneer Scientist* (cit. note 5), p. 197. DRAKE, *Galileo Studies: Personality, Tradition, and Revolution*, Ann Arbor, University of Michigan Press, 1970, p. 277.

³⁴ DRAKE, *Galileo: Pioneer Scientist* (cit. note 5), p. 199.

³⁵ That it was to the detriment of his physics has been asserted by R. S. WESTFALL, *Force in Newton's Physics: The Science of Dynamics in the Seventeenth Century*, London, Macdonald, 1971, p. 88. This is quoted in full below at note 61.

because something is obvious, this does not mean that there is nothing to be learned from paying careful attention to it. The simple answer is that force was seen, in the early decades of the seventeenth century, as an occult notion, associated with active principles, vital spirits and other mysterious or inexplicable elements in Renaissance philosophy. It was the very fact that Galileo believed he could explain all phenomena in terms of motion, that made it important for him to expunge any suggestions that mysterious forces might be at work.

As far as I am aware only Max Jammer's study of *Concepts of Force* (1957) considers the occult aspects of the history of the notion of force, and he does so only briefly.³⁶ Although R. S. Westfall's magnificent *Force in Newton's Physics* (1971) looks back to the notion of force before Isaac Newton, it begins with Galileo and Descartes, saying nothing about previous developments which might have led both of them to reject force. There is the same lack of concern with anything before the advent of the great figures of the Scientific Revolution in all other discussions of force and dynamics. The history of ideas about force before Galileo, therefore, seems to me to remain an important desideratum for future historical research.

Force, in the sense which interests us here, was clearly *not* an Aristotelian concept. Aristotle believed that everything which moves must be (continually) moved by something else, and whatever does the moving must be in contact with the thing it moves (either by pushing or pulling, or, in the case of self-movers, by an internal act of the will). The new theories of force of impact or force of percussion which Galileo and others were introducing into the newly expanded science of mechanics would not have been seen as a radical departure from,

³⁶ MAX JAMMER, *Concepts of Force: A Study in the Foundations of Dynamics*, Cambridge, Mass., Harvard University Press, 1957, pp. 53-80.

or in any way incompatible with, these Aristotelian precepts, but these were not the theories of force that interest us.³⁷

We are concerned here with what could be called occult notions of force. So far, there has been no systematic survey of ideas about these kinds of forces. Clearly, such a survey would include theories of attractive (or repulsive) force such as the magnetic and electric forces, the force of gravity, and other occult phenomena which seemed to suggest the possibility of *actio in distans*.³⁸ These often seemed to be linked to the broader magical belief in sympathies and antipathies, which is to say the belief that there can be resonances and influences between different, but somehow corresponding, things in God's Creation. A common assumption, underwriting astrology for example, was the belief that the heavenly bodies corresponded with and could influence sublunar phenomena. Theories invoked to explain such remote influences assumed that, as well as light, heavenly bodies might radiate other kinds of physical influence. Light itself, particularly in what is usually referred to as the tradition of light metaphysics, was often held to be capable of exerting pressure or in some way stimulating motion in bodies upon which it fell. This was a belief which seems to have derived from Neoplatonic ideas about the cosmogonical role of light. Emanating from the Godhead at the Creation, light was held to have diffused throughout space, in some versions constituting space as it went, and in others concreting itself to form the various bodies of the

³⁷ On this aspect of Galileo's work see, for example, PETER MACHAMER, *Galileo's Machines, His Mathematics, and His Experiments*, in PETER MACHAMER (ed.), *The Cambridge Companion to Galileo*, Cambridge, Cambridge University Press, 1998, pp. 53-79.

³⁸ For a general survey see MARY B. HESSE, *Forces and Fields: The Concept of Action at a Distance in the History of Physics*, London, Nelson and Sons, 1961. STEPHEN PUMFREY, *Magnetical Philosophy and Astronomy, 1600-1650*, and J. A. BENNETT, *Magnetical Philosophy and Astronomy from Wilkins to Hooke*, both in, R. TATON and C. WILSON, eds, *The General History of Astronomy, Volume 2A: Planetary Astronomy from the Renaissance to the Rise of Astrophysics*, Cambridge, Cambridge University Press, 1989, pp. 45-53 and 222-230; JOHN HENRY, *Animism and Empiricism: Copernican Physics and the Origins of William Gilbert's Experimental Method*, «Journal of the History of Ideas», 62, 2001, pp. 99-119; idem, *Gravity and De gravitatione: The Development of Newton's Ideas on Action at a Distance*, «Studies in History and Philosophy of Science», 53, 2011; BRIAN P. COPENHAVER, *A Tale of Two Fishes: Magical Objects in Natural History from Antiquity through the Scientific Revolution*, «Journal of the History of Ideas» 52, 1991, pp. 373-98.

universe. In such emanationist traditions, often found in alchemical theorising, light was held to be a principle of activity within all bodies.³⁹ A major representative of these ideas was pseudo-Dionysius, whom we have just seen Galileo invoking at the end of his *Letter to Christina*.⁴⁰

This and closely related traditions which supposed other kinds of radiations emanating through the universe, gave rise in turn to the belief that created bodies might be endowed with their own spheres of activity or spheres of virtue, demarcating a surrounding space through which the body might exert its influence in various ways, often either by attraction or repulsion. Theories of the multiplication of species, originally intended to comprehend the nature of radiating virtues within an Aristotelian framework, also offered ways of speculating about the means of transmission of active principles from one body to another without any transfer of matter.⁴¹ Similar ideas were often couched in terms of the activity of spirits, whether conceived as subtle material principles, or entirely immaterial entities, or beings held to have their own special ontological status forming a bridge between the material and the immaterial realms. Even when conceived as material entities, these putative spirits were considered to be active principles, capable for example of initiating motions in the surroundings. For the English physician, William Harvey, «spirit is that which Hippocrates

³⁹ BRIAN COPENHAVER, *Astrology and Magic*, in C. B. SCHMITT and Q. SKINNER, eds, *The Cambridge History of Renaissance Philosophy*, Cambridge, Cambridge University Press, 1988, pp. 264-300; A. C. CROMBIE, *Robert Grosseteste and the Origins of Modern Science*, Oxford, Clarendon Press, 1953; BETTY JO TEETER DOBBS, *The Janus Faces of Genius: The Role of Alchemy in Newton's Thought*, Cambridge, Cambridge University Press, 1991; JOHN HENRY, *Magic and Science in the Sixteenth and Seventeenth Centuries*, in R. C. OLBY et al., eds, *Companion to the History of Modern Science*, London: Routledge, 1990, pp. 583-96; RON MILLEN, *The Manifestation of Occult Qualities in the Scientific Revolution*, in M. J. OSLER and P. L. FARBER, eds, *Religion, Science and Worldview: Essays in Honor of Richard S. Westfall*, Cambridge, Cambridge University Press, 1985, pp. 185-216; JOHN HENRY, *Occult Qualities and the Experimental Philosophy: Active Principles in pre-Newtonian Matter Theory*, «History of Science», 24, 1986, pp. 335-81; LYNN THORNDIKE, *A History of Magic and Experimental Science*, 8 vols, New York, Columbia University Press, 1923-58.

⁴⁰ I am committed to the view, of course, that Galileo drew upon pseudo-Dionysius in the *Letter to Christina* in an insincere way, simply to forward his cause. So, my comment here should not be taken to imply that Galileo approved of this Dionysian notion of force.

⁴¹ See HENRY, *Occult Qualities and the Experimental Philosophy* (cit. note 39); idem, *Robert Hooke, the Incongruous Mechanist*, in MICHAEL HUNTER and SIMON SCHAFER, eds, *Robert Hooke: New Studies*, Woodbridge, Boydell Press, 1989, pp. 149-80; and idem, *Gravity and De gravitatione* (cit. note 38).

called *impetuum faciens*, namely whatsoever attempts anything by its own endeavour and arouses any motion with agility and vehemence, or initiates any action». ⁴²

Sources of information, or claims and speculations, about the nature of such emanations, multiplications, spirits, active principles, spheres of activity, and other ideas closely related to, or giving rise to, occult notions of force, can be seen to have originated from a number of different, though frequently overlapping, sources. Sympathies and antipathies and the notion of correspondences between different parts of Creation were mainstays of the Medieval natural magical tradition. The Galenic tradition in medicine developed ideas about occult qualities including attractions and repulsions. Newly revived Neoplatonic traditions, and recent eclectic attempts to develop new philosophies, such as those by Ficino, and the Italian Nature Philosophers, Telesio, Patrizi and Bruno, made intellectuals more aware of emanationist theories such as those of light metaphysics, while new alchemically inspired cosmologies like those of Paracelsus and Joan Baptista van Helmont combined emanationism with notions of active spirits. ⁴³ The theory of the multiplication of species was developed in the thirteenth century by Roger Bacon, renowned during the early modern period as one of the most noted magicians of his time. These theories had the powerful advantage among Renaissance thinkers of Ancient pedigrees, being found in Hermetic and other Neoplatonic writings which were supposed to reflect the oldest wisdom known to man. ⁴⁴ Even the

⁴² WILLIAM HARVEY, *Disputations touching the Generation of Animals*, translated by G. WHITTERIDGE, Oxford, Blackwell, 1981, Chapter 71, p. 374. See D. P. WALKER, *The Astral Body in Renaissance Medicine*, «Journal of the Warburg and Courtauld Institutes», 21, 1958, pp. 119-33; D. P. WALKER, *Medical Spirits in Philosophy and Theology from Ficino to Newton*, in idem, *Music, Spirit and Language in the Renaissance*, London, Variorum, 1985; and JOHN HENRY, *The Matter of Souls: Medical Theory and Theology in Seventeenth-Century England*, in R.K. FRENCH and A. WEAR, eds, *The Medical Revolution in the Seventeenth Century*, Cambridge, Cambridge University Press, 1989, pp. 87-113.

⁴³ See, for example, COPENHAVER, *Astrology and Magic* (cit. note 39); THORNDIKE, *History of Magic* (cit. note 39); and CHARLES WEBSTER, *From Paracelsus to Newton: Magic and the Making of Modern Science*, Cambridge, Cambridge University Press, 1982.

⁴⁴ On Bacon see GEORGE MOLLAND, *Roger Bacon as Magician*, «Tradition», 30, 1974, pp. 445-60. On the Hermetic writings see COPENHAVER, *Hermetica* (cit. note 11). On the veneration of a supposedly superior Ancient wisdom see D. P. WALKER, *The Ancient Theology*, London, Duckworth, 1972.

medieval theory of multiplication of species could be seen as a clarification of much older, Aristotelian ideas.⁴⁵ In the case of light metaphysics, of course, it dovetailed perfectly with the Creation account in the book of Genesis in which God created the world by first creating light.⁴⁶

But these are just some of the more obvious ideas about occult forces and their most likely sources. What is required is a much more systematic survey of Medieval and Renaissance ideas, in order to draw up a much fuller catalogue of ideas on causative forces in pre-modern attempts to understand the natural world. The full picture will be much richer than this brief sketch. But even if there are no new elements in the full picture, even if my brief survey has touched upon all the relevant ideas, it seems to me that a full consideration of the history of these ideas will greatly enhance our understanding of the history of science. These are matters, then, that I hope will be fully explored in future. For the time being, however, it seems safe to say that there were numerous Renaissance and early modern thinkers who were clearly influenced by these occult notions of force.⁴⁷ At a time when intellectuals assumed that real wisdom had been known in the past, and had been successively lost since the Fall of man, the Ancient pedigree of these ideas strongly suggested the truth of such notions.⁴⁸ Furthermore, there was nothing here that would have seemed inherently implausible and much that must have seemed potentially highly fruitful in understanding the operations of nature. Even so, it is very clear that not everyone agreed. In particular, it seems perfectly clear that all such ideas were anathema to Galileo.

⁴⁵ D. C. LINDBERG, *Theories of Vision from al-Kindi to Kepler*, Chicago, University of Chicago Press, 1976.

⁴⁶ See CROMBIE, *Robert Grosseteste* (cit. note 39).

⁴⁷ COPENHAVER, *Astrology and Magic* (cit. note 39); COPENHAVER, *Tale of Two Fishes* (cit. note 38); HENRY, *Occult Qualities* (cit. note 39); MILLEN, *Manifestation of Occult Qualities* (cit. note 39); THORNDIKE, *History of Magic* (cit. note 39).

⁴⁸ WALKER, *Ancient Theology* (cit. note 44)

For the most part Galileo manages to avoid discussing any such occult notions of force, preferring to stick to a usage of the term which clearly derives from the mathematical traditions of statics and mechanics. But he cannot avoid it when he comes to present his theory of the tides in the Fourth Day of the *Dialogo*. As is well known, it is at this point that Galileo publicly rebukes Kepler for perpetuating the view that the tides are caused by some kind of sympathetic attraction between the Moon and the waters of the seas.

But, among all the great men who have philosophized about this remarkable effect, I am more astonished at Kepler than at any other. Despite his open and acute mind, and though he has at his fingertips the motions attributed to the earth, he has nevertheless lent his ear and his assent to the moon's dominion over the waters, to occult properties, and to such puerilities.⁴⁹

But this was by no means an original idea with Kepler, and I believe it is a sign of how important it was to Galileo to dismiss this occult notion that he mentioned Kepler by name. He might have dismissed the notion in general terms, but since one of the leading astronomers of the day presented it favourably, Galileo felt the need to be explicit in his denunciation. Simplicio had already told readers, however, that those who refer the tides to the moon, «saying that this has a particular dominion over the waters», «are many», and he briefly mentioned one or two theories about the nature of that dominion, one being attraction, another being the ability to rarefy the waters by temperate heat.⁵⁰ Interestingly, rejection of this occult influence of the Moon is an issue that unites all three of the interlocutors in the *Dialogo*. Sagredo interrupts Simplicio to say that it is a waste of time to relate these theories, and much more to bother to refute them, Salviati (representing Galileo) denies them, and Simplicio, for his part, doubts whether the true cause has yet been discovered.⁵¹

⁴⁹ GALILEO, *Dialogo* (cit. note 27), p. 462.

⁵⁰ GALILEO, *Dialogo* (cit. note 27), p. 419.

⁵¹ GALILEO, *Dialogo* (cit. note 27), p. 421.

But Simplicio goes on from here to say that the impossibility of explaining the tides in a way that is «conformable to natural matters» suggests that it is «a supernatural effect and, therefore, miraculous and unsearchable to the understandings of men». Sagredo points out that Simplicio is here taking the standard Aristotelian line since Aristotle «ascribes to miracles all things whose causes are hidden».⁵² Kepler and other occultist philosophers would have denied this suggestion, believing that it was possible for something to have occult, but nonetheless, natural (or secondary) causes. While Galileo, for his part, believed that he could use the motion of the Earth to show that the cause of the tides was neither miraculous nor occult. As far as he was concerned, his tidal theory not only provided evidence for the motion of the Earth (at least for Galileo), but it also explained how the tides should seem to depend upon the Sun and on the Moon without the Sun or Moon having «anything to do with oceans or with waters.» In other words, Galileo not only believed he could give a purely kinematic explanation of the tides, but also that this explanation could simultaneously explain why it might look to the unwary as though the Moon had an occult influence on the seas.⁵³

The latter aspect of his argument is complex and cannot be fully expounded here, but essentially it depends upon seeing the Moon's rotation around the Earth as analogous to a regulating mechanism in a clock. Galileo describes the movement of weights of lead nearer or further from the pivot point of «a certain stick which is free to swing horizontally» which vary the frequency of the stick's oscillations and so adjust the clock's timekeeping. The motion of the Moon around the Earth inevitably brings it (the Moon) sometimes closer to the Sun and sometimes further away and this effects the motion of the Earth-Moon system as it revolves around the Sun, alternately slowing it down and speeding it up. These changes in the

⁵² GALILEO, *Dialogo* (cit. note 27), p. 421.

⁵³ GALILEO, *Dialogo* (cit. note 27), p. 454.

Earth's motion effect the motions of the waters, as can be seen in the rising and falling of the tides. In the end Salviati triumphantly declares:

Now you see that the cause of the monthly period resides in the annual motion; and, withal, you see how much the moon is concerned in this business, and how it is therewith connected, without having anything to do with either seas or waters.⁵⁴

I believe that Galileo's vigorous denunciation of Kepler and others who would explain the tides by occult attractions, and his own concern to reduce apparent occult interactions to a kinematic explanation analogous to motions in a clock, strongly suggests that his opposition to the use of force stemmed from its occult associations. This seems to be reinforced by the fact that he otherwise passes over notions of force in silence. His account of the Earth-Moon system as a regulating device which in turn effects the tides, and which we have just looked at, contains a number of references to «the force which moves the earth and the moon around the sun»,⁵⁵ but this and other occasionally invoked «motive forces», as we've seen, are simply taken for granted and never discussed.

The only exceptions to this that I am aware of look like attempts to suggest that the seemingly occult force of gravitational attraction might be reduced to nothing more than an impressed force or *impetus*, analogous to Galileo's kinematic explanation of projectiles. Consider, for example, the discussion in the *Dialogo* following from Salviati's famous claim that we know nothing of the essence of what we all know is «'called' gravity». Given our ignorance of the nature of gravity, it is perfectly possible that the internal principle of

⁵⁴ GALILEO, *Dialogo* (cit. note 27), pp. 449-54, p. 454. Galileo's theory of the tides is perhaps not quite as absurd as most recent scholarship has tended to portray it. See, for example, DRAKE, *Galileo Gleanings X: Origin and Fate of Galileo's Theory of the Tides*, «Physis», 3, 1961, pp. 185-94, and PAOLO PALMIERI, *Re-examining Galileo's Theory of the Tides*, «Archive for the History of the Exact Sciences», 53, 1998, pp. 223-375. But see Ron Naylor, *Galileo's Physics for a Rotating Earth*, in JOSE MONTESINOS and CARLOS SOLIS (eds), *Largo campo di filosofare: Eurosposium Galileo 2001*, Las Palmas, Fundacion Canaria Orotava de Historia de la Ciencia, 2001, pp.337-55.

⁵⁵ GALILEO, *Dialogo* (cit. note 27), pp. 452, 453.

downward movement exhibited during fall may be no different, Salviati argues, from the *impetus* which carries a projectile upwards. Impetus is imparted to a body by the act of projection so that the motion carries on after contact with the projector has ceased.

Gravitational fall, Salviati suggests, may simply be caused by a downward impetus. The argument is taken no further and remains merely suggestive, but the clear implication seems to be that motion due to gravity might simply be the result of an impressed force somehow imparted kinematically to the falling body. Although Galileo admits that he does not fully understand the nature of impetus itself, he makes it clear that its mysteriousness lies in its status as an element in a moving body. In other words, how the impetus resides in the body and how it performs its function while it is there. There is no mystery, however, about how impetus is imparted to, or imposed upon, a body, since it is a purely kinematic process. Just as a lever may be moved by a man pushing or pulling on it, so a projectile can be given impetus by a man throwing it. If gravitational fall is the result of impetus, as Salviati is made to suggest, then it too would be produced kinematically.⁵⁶

Similarly, in the *Discorsi* when the interlocutors are made to bring attention to the cause of gravitational acceleration, they do so only to allow Salviati (and Galileo) to dismiss this as a futile endeavour:

The present does not seem to be the proper time to investigate the cause of the acceleration of natural motion concerning which various opinions have been expressed by philosophers, some explaining it by attraction to the center, others to repulsion between the very small parts of the body, while still others attribute it to a certain stress in the surrounding medium which closes in behind the falling body and drives it from one of its positions to another. Now, all these fantasies, and others, too,

⁵⁶ GALILEO, *Dialogo* (cit. note 27), pp. 234-36.

ought to be examined; but it is not really worthwhile. At present it is the purpose of our Author merely to investigate and to demonstrate some of the properties of accelerated motion (whatever the cause of this acceleration may be)...⁵⁷

It seems, then, that for the most part Galileo evaded consideration of forces in his physics; only occasionally, as in the case of the moon effecting the tides or acceleration due to gravity, would he confront the issue, and then merely in a highly speculative and inconclusive way. In these cases he made it clear that he dismissed occult views of force, and his speculations can be seen as hints as to how occult forces might be explained away. It is instructive in this regard to compare Galileo's discussion of Gilbert's magnetic theories with Kepler's. Kepler makes full use of the cosmological, and occult, implications of Gilbert's work, using magnetism as a cosmic force to prefigure Newtonian gravitation, and like Newtonian gravity capable of acting at a distance. Galileo, by contrast, merely acknowledges Gilbert's proof that the Earth itself is a giant magnet, before focussing upon the use of armatures to increase the lifting powers of magnets.⁵⁸ Once again, Galileo avoids any discussion of occult matters. Even his discussion of lifting by magnets describes *touching* the armatured magnet to an iron weight so that it can be lifted—there is no discussion, for example, of how large a weight can be made to leap up to a magnet held at a distance. Koyré suggested that Galileo did not embrace the cosmological aspects of Gilbert's *De magnete*, in particular did not adapt it (as Kepler did) to explain gravitational phenomena, «because it was neither mathematical nor

⁵⁷ GALILEO GALILEI, *Dialogues Concerning Two New Sciences*, translated by Henry Crew and Alfonso de Salvio, New York, Dover, 1954, pp. 165-6. I refer to this subsequently as GALILEO, *Discorsi*.

⁵⁸ GALILEO, *Dialogo* (cit. note 27), pp. 399-415.

even mathematisable.»⁵⁹ It seems to me, however, that the occult nature of magnetism, and Gilbert's account of it, was the real stumbling block.⁶⁰

For R. S. Westfall, Galileo's refusal to allow forces of attraction was to prove highly detrimental to the development of science:

...the mechanical philosophy sometimes functioned directly to obstruct the science of mechanics. The question of attraction summarises the problem. On the one hand, the mechanical philosophy hung the label «occult» on the very word «attraction» and refused to admit the concept into natural philosophy. On the other hand, the idea of attraction offered to mechanics the handiest vehicle to a consistent and simple conception of force, especially in the model of free fall. The dilemma that Galileo had faced, which made it impossible for him to see free fall as the paradigm case of dynamics, was generalised for the entire seventeenth century by the mechanical philosophy.⁶¹

Although I am generally in agreement with what Westfall says here, I think it is important to avoid the assumption that the early mechanical philosophers, and especially Galileo, were 'misled' or 'mistaken' in some way by refusing to accept the notion of attraction and other occult kinds of force. Westfall, of course, had the benefit of hindsight and knew that the Newtonian achievement was going to be based on assuming that free fall, and numerous other phenomena, could be explained in terms of a force of attraction operating at a distance (an idea which Westfall says «ultimately did function as midwife to the birth of

⁵⁹ ALEXANDRE KOYRÉ, *Galileo Studies*, Hassocks, Harvester Press, 1978, p. 188.

⁶⁰ On Gilbert's cosmological use of magnetism see JOHN HENRY, *Animism and Empiricism: Copernican Physics and the Origins of William Gilbert's Experimental Method*, «Journal of the History of Ideas», 62, 2001, pp. 99-119.

⁶¹ WESTFALL, *Force in Newton's Physics* (cit. note 35), p. 88.

mechanics»⁶²). It may have seemed to Westfall, therefore, that Galileo simply made an unfortunate error of judgement. It seems clear, however, that Galileo rejected the notion of force of attraction quite deliberately, precisely because it was occult. For Galileo, one of the most important aspects of kinematics was that, by excluding all concepts of force except force of percussion and other clearly intelligible notions of force deriving from the mathematical tradition of mechanics, it helped to diminish the considerable power of occult philosophies which were all too prevalent among would-be reformers of natural philosophy.

Galileo's Kinematics

It may be objected to my claims that, whether Galileo avoided overt discussion of forces or not, the force of gravity was always there, especially when he was considering what he called «naturally accelerated motion». In what follows, I want to try to show that Galileo's strategy in his philosophical discussions was always to set-up his discussions in such a way that force, including the force of gravity, was no longer relevant (or seemed no longer to be relevant) to the point at issue. In other words, Galileo consistently tried to write forces, including the force of gravity, out of his account. Before going any further, it is perhaps worth commenting on the fact that Galileo did not routinely talk of «acceleration due to gravity» but chose to speak instead of «naturally accelerated motion». As we shall see, when he finally states his law of free fall in the *Discorsi*, gravity is nowhere to be seen, and the accelerations are just something that naturally occur.

One of the most effective ways that Galileo uses to do away with force, is by developing what is often referred to as «circular inertia», the notion that once moving in a circle with uniform speed a body will continue to so move indefinitely. Those, like Alexandre Koyré,

⁶² WESTFALL, *Force in Newton's Physics* (cit. note 35), p. 264.

who believe that Galileo seriously developed this notion in order to avoid confronting issues involving the physical cause of gravity, take consolation in the fact that, although Galileo's thinking here is sadly inadequate, the great man at least came close to hitting upon the useful idea of inertia. Koyré and like-minded assessors of Galileo's achievement tend to take at face value, therefore, the suggestions early on in the *Dialogue on the Two Chief World Systems*, which are circumstantially supported later on in the work, that Galileo believes circular motion to be the only natural kind of motion and that, this being so, no explanation is needed as to why the planets, including the earth, continue to move in perfect circles and with uniform motions around the Sun. When Salviati, in the *Dialogue*, persuades Simplicio that a smooth ball of polished brass rolling on a glassy-smooth plane that is perfectly flat will neither speed up nor slow down, as it would if moving one way or another on an inclined plane, and that such a perfectly flat plane would, in fact, have to follow the curvature of the Earth (neither receding from nor approaching the Earth's centre), it looks very much as though he is attempting to show how the earth itself can be assumed to be rolling perpetually around the Sun.⁶³

For Drake and other critics of Koyré this view seems to depend upon the assumption that Galileo was unaware of the details of Ptolemaic astronomy, much less the details of Keplerian astronomy, which undeniably showed that the planets could not be moving with perfectly circular and uniform motions. That Galileo could have been ignorant of the demands of technical astronomy is certainly unbelievable and so Drake and others have preferred to suppose that Galileo must have had an alternative, albeit hidden, account of the motion of the planets.⁶⁴ Although Drake is forceful in his rejection of the idea of circular

⁶³ KOYRÉ, *Galileo Studies* (cit. note 59), pp. 154-75.

⁶⁴ Drake was undeniably a great Galileo scholar but he evidently had a blind spot when it came to what has come to be called «circular inertia». Throughout his works he denies that Galileo ever accepted the idea that bodies once set revolving on a circle around a centre of gravity would continue to move uniformly around that

inertia and its alleged role in accounting for planetary motions, he remains resolutely agnostic about alternative accounts. Rather than try to discover an alternative theory in Galileo's writings, he prefers to stand by his assertion that Galileo did not indulge in providing causal explanations, and to insist that, if Galileo himself «did not offer a complete system of the universe», then «we need not construct one for him».⁶⁵ But while other scholars might agree that Galileo did not offer a complete system, some nevertheless remain optimistic that it might be possible to glean hints from his writings about the general tendency of his thoughts.

I subscribe to the Koyréan interpretation, and therefore have to try to understand how Galileo could claim, in the teeth of long acknowledged astronomical observations (and over twenty years after the appearance of Kepler's *Astronomia nova*), that planets move in perfect circles with uniform circular motion. It seems to me that the only way we can understand this is by analogy with Galileo's much cherished theory of the tides. It is evident that Galileo believed that his basic theory of the tides, based on the combined motions of the rotation of the Earth on its axis and its revolution around the Sun, in some sense went to the heart of the matter and revealed the essential truth of the phenomenon. Nevertheless, Galileo was also aware that messy physical contingencies, such as the varied depth of the seas, the surrounding topography which determined the orientation of the seas with regard to the motions of the Earth and so forth, must play a role in determining the all too varied motions of the tides. All of these extraneous conditions were sufficient, Galileo believed, to account for the many complexities and local variations in tide patterns. They should not be allowed, however, to mask the underlying truth about the motor of tidal movements, based on the Earth's

centre. Drake seems to have seen this as fatal to Galileo's reputation as a physicist («historians invented a notion discreditable to him as a physicist»—*Galileo: Pioneer Scientist*, cit. note 4, p. 229), and therefore would not countenance it. The ways in which he tries to escape this evidently correct interpretation of Galileo's views on circular motion is in some cases truly astonishing. See, for example, Drake, *Galileo Gleanings XVII: the Question of Circular Inertia*, «Physis», 10, 1968, pp. 282-98.

⁶⁵ DRAKE, *Galileo Studies* (cit. note 33), p. 277.

combined motions, which Galileo had discovered (or so he believed). Similarly, Galileo must have assumed that the messy realities of planetary movements which had led Ptolemy to introduce eccentrics, epicycles and equants, and which had led Kepler to his first two laws of planetary motion (determining the continual acceleration and deceleration of planets on elliptical orbits) were contingent complexities which did not invalidate the fundamental truth of his account of planetary motions in terms of «circular inertia».⁶⁶

Before moving on, it is perhaps worth re-iterating the main point about «circular inertia»: it is held to work precisely because there is no interference from any mysterious force—as Galileo introduces the notion into his *Dialogo* he does so by writing gravity out of the story. Simplicio is asked to consider a sphere on a perfectly smooth indefinitely extended plain set at an incline, and to describe what would happen to the sphere. Simplicio has no hesitation in saying it would continually accelerate if left to move down the slope, and would rapidly decelerate to a stand-still if pushed up the slope. The crucial move comes next, when Salviati asks Simplicio what would happen if the indefinitely extended plane were set perfectly horizontally. There is no reason now why the sphere should speed up or slow down, because gravity has been prevented from taking part. If set in motion, the sphere will now move with whatever speed is imparted to it, and will do so indefinitely. It is undeniable, of course, that any such «horizontal» plane has to be defined in terms of a central point of gravitational attraction—the horizontal plane that Salviati describes, as Simplicio accepts, would be a smooth sphere enveloping the Earth (strictly, circumscribing the Earth's centre of gravity). Galileo could not escape from this recalcitrant fact, but he could claim to have made the

⁶⁶ After all, it is important to note that Kepler himself did not entirely abandon the notion of circular orbits, or celestial spheres, after the publication of his *Astronomia nova* in 1609 (which included his first two «laws» of planetary motion). See J. BRUCE BRACKENRIDGE, *Kepler, Elliptical Orbits, and Celestial Circularity: A Study in the Persistence of Metaphysical Commitment*, «Annals of Science», 39, 1982, pp. 117-43. If the discoverer of elliptical orbits could maintain a belief in «celestial circularity», it is hardly surprising that Galileo should do so too.

centre of gravity irrelevant to his discussion, and to his explanation of the perpetual movement of the sphere. The sphere moved the way it did precisely because gravity was unable to affect it. Consequently, the movement of the sphere did not depend on any mysterious force, but merely on the fact that it was set in motion at some point by a mover. In modern terms it is a kinematic account, not a dynamic one.

Of course, a modern reader might object that Galileo had not really removed gravity (how could he?), but merely countered its effects by means of the supposed indefinitely extended horizontal plane. For bodies to move perpetually and with uniform motions Galileo «needed to have them supported by imaginary planes», Koyré pointed out, «so as thereby to counteract the unavoidable action of gravity.»⁶⁷ But Galileo's thinking long preceded the establishment of Newton's third law of motion (that action and reaction are equal and opposite), and it seems perfectly clear that Galileo regarded the horizontal planes he called upon to be required only by the nature of his illustrative examples (as in the case of a ship «having once received some impetus through the tranquil sea would move continually around our globe without ever stopping...».⁶⁸ If we consider his «cosmogonical fancy», suggested in the First Day of the *Dialogo*, for example, we can see that Galileo did not consider the presence of a physical plane to be in any way crucial to his account of perpetual circular motion. When God created Jupiter, for example, Galileo supposed that

We may say with Plato that at the beginning He gave it a straight and accelerated motion; and later, when it had arrived at that degree of velocity, converted its straight motion into circular motion whose speed thereafter was naturally uniform.⁶⁹

⁶⁷ KOYRÉ, *Galileo Studies* (cit. note 59), p. 239.

⁶⁸ OG, V, pp. 134-5; cited from DRAKE, *The Concept of Inertia*, in idem, *Essays on Galileo and the History and Philosophy of Science*, Volume 2, Toronto: University of Toronto Press, 1999, p. 143.

⁶⁹ GALILEO, *Dialogo* (cit. note 27), p. 21, see also p. 29.

Moreover, in his *Mechanics* of 1601 Galileo wrote «That heavy bodies, all external and adventitious impediments being removed, can be moved in the plane of the horizon by any minimum force.»⁷⁰ It was the ‘plane of the horizon’ in the abstract that was crucial, not any physical plane.

But if Galileo successfully contrives to make gravity irrelevant to his account of how the Earth and other planets can perpetually move around the Sun, surely he must acknowledge the role of gravity in free fall? Astonishingly, even here, in his discussions of what we would unthinkingly refer to as bodies accelerating due to gravity, Galileo still organises his accounts in such a way that he can avoid, or evade, consideration of gravity.

Consider, for example, Galileo’s controversial account in the *Dialogo* of the descent of a weight from the top of a tower. Salviati is made to suppose that the actual trajectory of the descending weight might be along a vertical circle whose diameter stretches from the top of the tower to the centre of the Earth. The weight’s descent from the top to the bottom of the tower (which seems to an onlooker to follow the wall of the tower straight down) is actually movement along an arc of this supposed circle. It is evident from Galileo’s diagram (which should be consulted), and from the geometry of the set-up, where the descending weight will be in relation to the tower as the tower moves with the Earth, and the weight follows its course towards the centre of the Earth. As Galileo says, the points along the side of the tower corresponding to successive points of descent of the weight «become more distant from the top of the tower in an ever increasing proportion, and that is what makes its straight motion along the side of the tower show itself to be always more and more rapid.»⁷¹

⁷⁰ I quote the *Mechanics* from DRAKE, *Galileo: Pioneer Scientist* (cit. note 5), p. 108.

⁷¹ GALILEO, *Dialogo* (cit. note 27), p. 165.

The point of this, however, as Galileo goes on to suggest, is that what looks like accelerated motion (more and more rapid) is really only an illusion caused by the compounded motions of the Earth and of the line of descent of the weight. In fact, Galileo claims, «the body really moves in nothing other than a simple circular motion, just as when it rested on the tower it moved with a simple circular motion.» Simple circular motion is, of course, uniform circular motion. Consequently,

the true and real motion of the stone is never accelerated at all, but is always equable and uniform. For all these arcs marked equally on the circumference CD [i.e. the circle drawn out by the movement of the tower as the Earth rotates], and corresponding arcs marked on the circumference CI [i.e. the vertical circle along which the stone descends], are passed over in equal times. So we need not look for any other causes of acceleration or any other motions, for the moving body, whether remaining on the tower or falling, moves always in the same manner; that is, circularly, with the same rapidity, and with the same uniformity.⁷²

Drake points out that this was presented by Galileo merely as a «bizzarria», and later dismissed as a «scherzo», but it is impossible to dismiss it out of hand. It seems to suggest that Galileo might really have believed, if only for a while, that he could explain accelerated motions (or explain them away) in terms of the motions of the Earth—in the same way that he believed he could explain the tides in terms of the motions of the Earth. As Sagredo is made to conclude:

according to these considerations, straight motion goes entirely out of the window and nature never makes any use of it at all. Even that use which you granted to it at the beginning, of restoring to their places such integral, natural bodies as were separated

⁷² GALILEO, *Dialogo* (cit. note 27), p. 166.

from the whole and badly disorganized, is now taken away and assigned to circular motion.

Salviati, speaking as ever for Galileo, immediately responds that this would «necessarily follow» if the terrestrial globe had been «proved to move circularly», which he admits has not yet been done.⁷³

Another indication that Galileo took this proposal more seriously than he was willing to admit explicitly, is that he did not dismiss it even though he knew it did not quite fit in with his work on parabolic trajectories. Even in the *Dialogo* Salviati is made to offer a few words of caution: «But that the descent of heavy bodies does take place in exactly this way, I will not at present declare; I shall only say that if the line described by a falling body is not exactly this, it is very near to it.»⁷⁴ But, more to the point, Galileo seems to suggest that he hoped to reconcile this proposal with parabolic (as opposed to circular) lines of descent in a letter he wrote to Pierre Carcavy in 1637. Carcavy had notified Galileo that Pierre Fermat, extending the motion of the weight to the centre of the Earth, had corrected the line of descent from a circle to a kind of spiral. The trajectory from the top of the tower to the bottom, Galileo now points out, would in fact be a «parabolic line», and this, if extended to the centre of the Earth, would continually depart from the Earth's axis. After suggesting that Fermat's critique might have been more damaging had he pointed this out, Galileo goes on to partially defend his original position: «I did at least make [the descent] to end at the centre [of the Earth], where I am sure projectiles would go to end...»⁷⁵ It seems, anyway, that Galileo was well aware that there were problems with this scenario, and yet he chose to use it

⁷³ GALILEO, *Dialogo* (cit. note 27), p. 167. Sagredo's reference to things discussed «at the beginning» refers to discussion on the First Day, when Salviati suggested «straight motion serves to transport materials for the construction of a work; but this, once constructed, is to rest immovable—or, if movable, is to move only circularly» GALILEO, *Dialogo* (cit. note 27), p. 20. DRAKE, *Galileo Gleanings XVI: Semicircular Fall in the Dialogue*, «Physis», 10, 1968, pp. 89-100.

⁷⁴ GALILEO, *Dialogo* (cit. note 27), p. 167.

⁷⁵ OG, XVII, pp. 89-90; I quote this from DRAKE, *Galileo Gleanings XVI* (cit. note 73), p. 67.

anyway. The opportunity to show that it might be possible to dispose of accelerated motion by showing it to be an illusion caused merely by the combination of two other (circular) motions was just too good to pass up.⁷⁶

Stillman Drake pointed out that in his early *De motu* Galileo believed that acceleration was «evanescent and unimportant», but by 1602, when he was experimenting with pendulums and with bodies falling along concave surfaces, Drake supposed that Galileo must have recognised «the importance of acceleration».⁷⁷ But I believe the attempt in the *Dialogo* to show that a body falling from the top of a tower on a rotating Earth might seem to accelerate when really it does not, shows that throughout much of his career Galileo did not completely concede the importance of acceleration. Be that as it may, it is certainly clear that he never accepted the view that acceleration was due to a mysterious force, whether called gravity or anything else.

Although nothing corresponding to this discussion appears in the *Discorsi*, it is still very evident there that Galileo nowhere discusses gravity or any other cause of «naturally accelerated motion». Once again, he carefully organises the discussion throughout so that the cause of accelerated motions is evaded. This is very evident, for example, in the famous presentation of his definition of naturally accelerated motion:

When... I observe a stone initially at rest falling from an elevated position and continually acquiring new increments of speed, why should I not believe that such increases take place in a manner which is exceedingly simple and rather obvious to everybody? If now we examine the matter carefully we find no addition or increment

⁷⁶ But see also NAYLOR, *Galileo's Physics for a Rotating Earth* (cit. note 54), pp. 340-42, and 349-50, where he points to fatal flaws in this argument.

⁷⁷ DRAKE, *Galileo's 1604 Fragment on Falling Bodies (Galileo Gleanings XVIII)*, «British Journal for the History of Science», 4, 1969, pp. 340-58: 349.

more simple than that which repeats itself always in the same manner. This we readily understand when we consider the intimate relationship between time and motion; for just as uniformity of motion is defined by and conceived through equal times and equal spaces (thus we call a motion uniform when equal distances are traversed during equal time-intervals), so also we may, in a similar manner, through equal time-intervals, conceive additions of speed as taking place without complication; thus we may picture to our mind a motion as uniformly and continuously accelerated when, during any equal intervals of time whatever, equal increments of speed are given to it.⁷⁸

Refusing to recognise any significant difference between uniform and accelerated motion, Galileo provides a kinematic definition in each case. It is Sagredo, not Salviati, who subsequently asks «what causes the acceleration in the natural motion of heavy bodies?», and who speaks of the «force of gravitation», and only Simplicio who enters into the discussion. When Salviati does interject it is only to curtail this discussion. It is here that the passage already quoted appears, in which Salviati says, «The present does not seem to be the proper time to investigate the cause of the acceleration of natural motion...»⁷⁹

Sagredo and Simplicio are allowed another brief exchange later when Sagredo, taking up Galileo's claim that the descent of bodies along any chord of a vertical circle take the same time (Theorem VI, Proposition VI), envisages a continually expanding circle analogous to the circle caused by dropping a stone into water.⁸⁰ The point is that radiation outwards from the centre of a horizontal circle, or downwards in all directions from the topmost point on the circumference of a vertical circle, gives rise to a series of continually expanding circles.

⁷⁸ GALILEO, *Discorsi* (cit. note 57), Third Day, p. 161.

⁷⁹ GALILEO, *Discorsi* (cit. note 57), pp. 165-7.

⁸⁰ GALILEO, *Discorsi* (cit. note 57), pp. 192-3.

Simplicio sees this as related to the creation of the spherical universe. Once again, Salviati intervenes only to curtail the discussion. On this occasion, however, he does not do so dismissively. «I have no hesitation in agreeing with you», he says, but regards it as beyond their ability to understand this mystery.⁸¹

It is worth lingering over this to consider the implications. I believe it is possible that Galileo did believe there was, as he made Simplicio say, «some great mystery hidden in these true and wonderful results». If so, he presumably believed that there was something here which confirmed his kinematic approach and might have enabled him to dismiss dynamic approaches. We can only speculate about that. However, it is worth noting that from our perspective we might have expected Galileo to take this line with regard to the earlier exchange between Sagredo and Simplicio about the cause of gravity. Galileo might have said words to the effect that «I have no hesitation in agreeing with you that there is a cause of gravity but it is beyond our ability to understand this mystery at present.» The fact that he did not say anything like this at this point in the discussion (on the cause of gravity), but did say it in response to Simplicio's «mystery related to the creation of the universe», surely seems to suggest that Galileo had no patience whatsoever with talk of mysterious forces or virtues. He could entertain mysteries which concerned movement along chords of a circle in equal times, but he had no time for suggestions that there might be a force of gravitation.

It is perhaps worth pointing out, also, that the most well known results of Galileo's study of free fall say nothing about the cause of acceleration. The fact that the spaces covered in equal times starting from rest follow the sequence of the odd numbers, and the related conclusion that the distances covered are directly proportional to the squares of the elapsed times, tell us

⁸¹ GALILEO, *Discorsi* (cit. note 57), p. 194.

nothing about why falling bodies accelerate. Similarly, the fact that Galileo showed that the acceleration had nothing to do with the weight of a body, and that all bodies fall at the same rate, must have strongly suggested to pre-Newtonian minds that gravity (whatever it might be) must be irrelevant. Galileo was perfectly correct in saying, when he wrote to Giovanni Battista Baliani in 1639, «I assume nothing but the definition of that motion with which I wish to deal, and whose events I wish to demonstrate... And premissing nothing more... I prove that the spaces passed... are in the squared ratio of the times...».⁸² Galileo premissed nothing more than motion. As Koyré rightly insisted, Galileo consistently refused «to see gravity as a natural quality of bodies», or «as a source or a cause of downwards motion».⁸³

Conclusion

I believe that Galileo's theory of the tides, which he arrived at around 1595, struck this latter day Archimedean as his own Eureka moment. It provided him with the insight that physical phenomena, even ones that seemed inescapably to depend upon occult forces, could in fact be explained only by motions, without premissing anything more. In some cases, the motions in question had to be compound motions deriving from the motion of the body and the motion of the Earth, but there was never any need to resort to forces or any other occult notions. In the *Dialogo* he tried to put his kinematics across in a bold and even blustering way, perhaps hoping that nobody among his readers would call his bluff. By the time he came to write the *Discorsi*, he was surely beginning to see that the theory of the tides, on which he had pinned so much, was no longer tenable.⁸⁴ Even so, the tidal theory could still exert an influence on

⁸² OG, XVIII, pp. 11-13; I quote this from DRAKE, *Galileo's New Science of Motion*, in M.L. RIGHINI BONELLI and WILLIAM R. SHEA (eds), *Reason, Experiment and Mysticism in the Scientific Revolution*, Canton, Watson Publishing International, 1975, pp. 131-56, p. 156.

⁸³ KOYRÉ, *Galileo Studies* (cit. note 59), p. 177.

⁸⁴ See NAYLOR, *Galileo's Physics for a Rotating Earth* (cit. note 54), pp. 350-53. Naylor seems to imply that Galileo's studies of the Moon's libration in 1637 indicate a capitulation to the lunar theory of the tides. But Galileo was nothing if not recalcitrant, and it seems to me that Galileo could have been hinting (he could do no more than that after his condemnation) that there might still be mileage in his idea that the rotations of the Earth-

other thinkers. As Wallace Hooper has recently suggested, a «history of the competing theories of the tides between 1590 and 1687 provides a modern reader with a pass key to the development of the emerging classical-mechanics-to-be over the same period.»⁸⁵ Putting it more simply, I would suggest that Galileo's kinematic account, in spite of its problems, played a major role in the development and up-take of the mechanical philosophy in the decades following its publication.

Furthermore, the failure of the tidal theory was not enough to make Galileo abandon the principles of kinematics. In the *Discorsi* Galileo was perhaps less bold than he had been in the *Dialogo*, being content to show «with what ease and clearness» he could deduce «from a single principle the proofs of so many theorems» about the way bodies move. That single principle was «naturally accelerated motion» but even that was defined without recourse to notions of force («we may picture to our mind a motion as uniformly and continuously accelerated when, during any equal intervals of time whatever, equal increments of speed are given to it.»). It seems to me, furthermore, that Galileo did not so much develop his kinematics in order to defend Copernicanism; rather, he became a Copernican because he needed a moving Earth to help him to develop his kinematic natural philosophy. The tidal theory depended on a moving Earth and pointed the way to how a moving Earth might be implicated in other physical phenomena. The development of Galileo's kinematics, therefore, led him to adopt Copernicanism, rather than the other way around.

Moon system as they circle the Sun could account for cyclical variations in the tides, by analogy with the lead weights on a tilting stick used to regulate clockwork (see above at note 54).

⁸⁵ WALLACE HOOPER, *Seventeenth-Century Theories of the Tides as a Gauge of Scientific Change*, in PALMERINO and THIJSEN (eds), *The Reception of Galilean Science of Motion* (cit. note 4), pp. 199-242, p. 201.

According to Stillman Drake Galileo was led by his inability to define force to reject the pursuit of causes and to turn instead to a physics based on laws of nature.⁸⁶ I do not think Galileo abandoned attempts to explain things in causal terms. On the contrary, his kinematics was seen by him as offering far more cogent, and readily intelligible, explanations of physical phenomena than any of the proliferating alternative speculative natural philosophies that were being offered by contemporary natural philosophers. The theory of the tides provides a causative account in terms of the motions of the Earth; the concept of «circular inertia» explains how it is that the Earth and the other planets can be in perpetual motion around the Sun.

Galileo did not reject causes, he merely rejected all occult causation. Even Drake, when illustrating what he took to be Galileo's rejection of causes, cited as examples sympathy and antipathy «or any other occult quality», Kepler's account of the tides, and gravity. There can be no doubt that Galileo was dead set against occult ideas and wanted to exclude them from his natural philosophy. He saw it as of the utmost importance, therefore, to exclude any notion of force which invoked actions at a distance, attractions, repulsions and the like, or which depended upon what he no doubt saw as vague and unaccountable terms like radiative virtues, or spheres of activity.⁸⁷

⁸⁶ See, for example, DRAKE, *Galileo's New Science of Motion* (cit. note 82), pp. 147, 153; and DRAKE, *Galileo Gleanings XVII* (cit. note 64), pp. 297-8. Furthermore, I believe it is anachronistic to see Galileo as turning instead to laws of nature. Drake meant by this that Galileo was content to talk in terms of natural regularities—laws of nature as nothing more than statements of what regularly happens in nature. Galileo was writing before Descartes codified precise laws of nature and completely transformed the role of laws in philosophical discourse. Moreover, when Descartes first introduced his concept of laws of nature they were presented as real causes in nature. The development of the notion of laws as nothing more than statements of perceived regularities followed later. See, FRIEDRICH STEINLE, *From Principles to Regularities: Tracing «Laws of Nature» in Early Modern France and England*, in LORRAINE DASTON and MICHAEL STOLLEIS (eds), *Natural Law, and Laws of Nature in Early Modern Europe: Jurisprudence, Theology, Moral and Natural Philosophy* (Aldershot: Ashgate, 2008), pp. 215-31; and JOHN HENRY, *Metaphysics and the Origins of Modern Science: Descartes and the Importance of Laws of Nature*, «Early Science and Medicine», 9, 2004, pp. 73-114. For a brief account of the historiography of Galileo's theory of causation, see the first part of Steffen Ducheyne, *Galileo's Interventionist Notion of Cause*, «Journal of the History of Ideas», 67, 2006, pp. 443-64..

⁸⁷ The notion of a «sphere of activity» is invoked in the *Dialogo* but by Simplicio: GALILEO, *Dialogo* (cit. note 27), p. 74.

Galileo's view was shared by Marin Mersenne, Thomas Hobbes, and no doubt others, and it became increasingly influential as Cartesianism, a fully formed and entirely kinematic system, took hold in Northern Europe.⁸⁸ For such thinkers the contemporary emphasis upon occult notions seemed philosophically unsound, methodologically unsupportable, or theologically dangerous. But their attitude to the occult was not shared by everyone, much less their attitude to force. For many, occult notions of force must have seemed potentially highly fruitful, and their drawbacks, such as implications that they depended upon action at a distance, could be seen to be overruled by taking a phenomenalist stance based on empiricism.⁸⁹ Each thinker no doubt had their own reasons for accepting or rejecting different ideas about the nature of force, and there is surely a great deal to be learned about the culture of late Renaissance and early modern natural philosophy from trying to uncover what those reasons were.

What is evident, however, is that throughout the sixteenth century reforming natural philosophers seemed to think that the occult held the key to finding a replacement system of philosophy, capable of replacing the comprehensive system of scholastic Aristotelianism. By the second half of the seventeenth century, however, the dominance of the mechanical philosophy and the continuing mathematization of the world picture, showed that things had dramatically changed. Natural philosophers who previously would have ignored, or paid scant attention to, what mathematicians were doing, now accepted that bodies in motion

⁸⁸ WILLIAM L. HINE, "Marin Mersenne: Renaissance Naturalism and Renaissance Magic", in BRIAN VICKERS, ed., *Occult and Scientific Mentalities in the Renaissance*, Cambridge, Cambridge University Press, 1984, pp. 165-76. There is no specific study of Hobbes's opposition to occult ideas but he was undeniably the most materialistic and strictly mechanistic of the English natural philosophers, see ALAN GABBEY, et al., "New Doctrines of Body and Its Powers, Place and Space", in D. GARBER and M. AYERS, eds, *The Cambridge History of Seventeenth-Century Philosophy*, 2 vols, Cambridge, Cambridge University Press, 1998, v. 1, pp. 553-623: 581-4. For indications of the triumph of Cartesian anti-occultism in Continental Europe consider the famous objections of Huygens and Leibniz to Newton's concept of gravity.

⁸⁹ KOYRÉ, *Galileo Studies* (cit. note 59), pp. 177-80; and HENRY, *Occult Qualities and the Experimental Philosophy* (cit. note 39).

offered much more intelligible explanations of physical phenomena than anything to be found in the occult sciences. Furthermore, having escaped from vague and unhelpful occult «explanations» of phenomena, of the kind found in Ficino, Fernel, and others, and having learned the lessons of kinematics, it became possible for natural philosophers to re-introduce forces and to turn kinematics into dynamics, as Newton and Leibniz and others were triumphantly to do.

It cannot be said that Galileo single-handedly brought about this change, but it is even more impossible to deny that he was one of the major figures. No other contemporary mathematician commanded the attention of natural philosophers the way Galileo did, and none could convey the philosophical import of their approach to physical phenomena and physical problems with anything like the clarity and impact of Galileo's *Dialogo* and *Discorsi*.⁹⁰ In the end, then, we could say that the importance of Galilean kinematics lies not only in how it helps us to understand the development of modern science, but also in how an investigation of the reasons why Galileo preferred to develop kinematics rather than dynamics, helps us to understand the broader philosophical and methodological attitudes, assumptions, and preoccupations which formed the intellectual background to the Scientific Revolution.

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⁹⁰ The full story of Galileo's impact on subsequent thinkers has yet to be told, but for a brief indication of the rapid diffusion of his ideas throughout Europe, see, for example, the opening remarks in ENRICO GIUSTI, *A Master and His Pupils: Theories of Motion in the Galilean School*, in PALMERINO and THIJSEN (eds), *The Reception of Galilean Science of Motion* (cit. note 4), pp. 119-35, p.119